NDT Technology Readiness

A P&WC Case Study

David M Craig

Senior Fellow & Mgr. NDT Technology
Fellow & Past National Chair – Canadian Institute for NDE (CINDE)

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<table>
<thead>
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<td>2. ECCN(s):</td>
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NDT TECHNOLOGY READINESS
A P&WC CASE STUDY

14th. Annual NDT Better Way Award Winners

P&WC
David Craig
Peter Boyd
Gerry Whitty
Francesco Finzi-Contini
Daniel Gagnon
Daniel Girard
Josee Caya

VIBRANT
Greg Weaver
Leanne Jauriqui
Eric Biedermann
Tom Williams
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Content

• Pratt & Whitney Canada (P&WC)

• NDT in the value stream

• Technology Readiness (TR)

• Case study

• Turbine blade re-design PCRT activity

• Statistical Process Control (SPC) using PCRT

• Summary
The six men who originally came to work for Canadian Pratt & Whitney Aircraft Limited in 1928. The company was founded by James Young (3rd from right), a Montreal businessman.
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P&WC Canadian Facilities

Manufacturing and R&D facilities across Canada

- Corporate headquarters
  Engine development, assembly & aftermarket
- Maintenance, repair & overhaul
- Component manufacturing
- Engine assembly
- Engine assembly & flight testing
- Altitude test facility with the National Research Council
- Engine development & assembly

Locations:
- GLACIER
  Cold weather testing & research facility
- Lethbridge
- Thompson
- Halifax
- Mirabel
- Longueuil
- Ottawa
- Mississauga

Export Classification: No Technical Data
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<tr>
<td>Québec</td>
<td>~5,000</td>
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<td>Ontario</td>
<td>~700</td>
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<td>International</td>
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<td>Poland</td>
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<td>United States</td>
<td>~850</td>
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<tr>
<td>Others (India, China, etc.)</td>
<td>~700</td>
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<td><strong>Total</strong></td>
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Global Customer Base

60,000+ Engines in Service
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Six Key Business Segments

**Corporate**
- Cessna Citation XLS
- Dassault F7X

**General Aviation**
- King Air C90GT
- Pilatus PC-12

**Regional**
- ATR 72
- Bombardier Q400

**Civil Helicopters**
- AgustaWestland AW139
- Sikorsky S76D

**Military**
- Embraer Super Tucano
- CASA C295

**Aftermarket**
- Customer First Centre
- Repair & Overhaul

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Pratt & Whitney Canada (P&WC) – 2016

Three Advanced Manufacturing Intelligent Cells $275M Cdn. investment
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NDT in the Value Stream

P&WC Value Stream Video
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NDT in the Value Stream

• The 2016 NDT Better Way Award Team -
  • Chief Engineers Office
  • Turbine Rotating Structures
  • Customer Management
  • Procurement – account manager
  • X-ray Computed Tomography (CT) technician and NDT
• X-ray Computed Tomography (CT). First CT scanner installed at P&WC over 20 years ago.
Some other NDT technologies evaluated over the years....

- Remote Acoustic Impact Doppler (RAID)
- *Resonant Ultrasonic Spectroscopy (RUS) (1994)*
- Alternative Current Potential Drop (ACPD)
- Sonic IR / Thermosonics / Vibrothermography
- ......
Technology Readiness (TR)

- Resonant Ultrasonic Spectroscopy (RUS) / Process Compensated Resonance Testing (PCRT) a 22 year journey....
Case Study...initial mandate...

- Systemic issue with turbine blades related to various casting flaws
- Eliminate unique casting flaws that are not detected by current inspection methods that result in quality escapes. These include, but are not limited to, cold shots, non-metallic inclusions, non-homogeneous material, under min. wall thickness, aluminum rich layer, etc.
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Typical casting anomalies

Cold Shot

Non-metallic inclusion

Sinuous interdendritic casting anomaly
• Connection made back to the early 90’s RUS work – full part inspection, quick, sensitive to material flaws, etc.

• Vibrant contacted and technology had matured significantly to Process Compensated Resonance Testing (PCRT)
  • Allows for normal process variation while still detecting target defects
  • Population characterization identifies outlier parts with singular defect conditions
  • Quantifiable output monitors part flow over time to show process or component drift outside of the norm
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PCRT system
The PCRT System applies pattern recognition to the entire resonance spectra of the component being tested.
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PCRT Analysis Tools

Z-Score Method
Outlier Screening / Process Monitoring

VIPR Method
(Targeted Defect)
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Casting pilot study

- 2400+ castings inspected

- VIPR sort had relatively good correlation with x-ray inspection data

- < 10 second inspection per casting
Quality issue attributed to shrinkage porosity
X-ray film review

- Review of production x-ray film (where available) of the casting revealed two issues –

- Shrinkage porosity in the vicinity of the blade pocket not detected during x-ray inspection

- Shrinkage porosity indication on the x-ray film but missed by the inspector

- 40% / 60% ratio
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Shrinkage porosity
Shrinkage porosity

- Equiaxed casting

- Shrinkage porosity difficult to detect and interpret using conventional film (orientation, grain diffraction (mottling), etc.)

- Digital Radiography (DR) and X-ray Computed Tomography (CT) utilized to select blades for VIPR training
Shrinkage porosity

- DR Image
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Shrinkage porosity

• DR Image

• Classified as “heavy” shrinkage porosity
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Shrinkage porosity

- CT slice
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PCRT inspection booth

- P&WC PCRT production inspection set-up
- Inspection service P&WC / Vibrant
- >140,000 blades inspected to VIPR
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VIPR progression (6 off)

• VIPR progression (6 off)

VIPR Rev 1-4
- Train to small number of confirmed defects
- Use conservative limits with lower yield to immediately quarantine suspect blades
- Yield 70-90%

VIPR Rev 5-6
- Further examine severity of defects relative to population
- Align targets with engine field performance data
- Re-test quarantined components
- Yield 95+%  
- 7000 blades scrapped
Event rate reduction

- Latest field data attributed to shrinkage porosity – 1 false negative (Rev 1 VIPR). Two post PCRT lead-the-fleet engines at over 6000hrs
Casting re-design

- In conjunction with the inspection activity, Engineering initiated a re-design of the casting

- Result: Improved creep life in the airfoil
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Statistical Process Control (SPC) using PCRT

• Since re-design: Automated production process monitoring of castings

• Z-score

• Incorporates a vision system for reading of the casting S/N (reduced human factor)

• Approx. 51,000 castings tested to-date

• Reject rate < 1.0%
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Statistical Process Control (SPC) using PCRT

Vibrant Robotic System Video
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Statistical Process Control (SPC) using PCRT
PCRT – emerging trend related to dimensional variations in blade castings

• Other limited studies are trending towards a dimensional variation in the blade profile of PCRT Outliers
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PCRT – emerging trend related to dimensional variations in blade castings
PCRT – the dilemma, quandary, predicament or impasse….

• In some cases, cause of resonance Outlier signal cannot be conclusively identified

• Relate this resonance difference to blade performance in an engine
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The TR Advantage

TRL 1-6
- Initial evaluation of technology in development mode
- 3222 casting study - showed sensitivity to X-ray indications

TRL 6
- Testing on real parts
- Additional inspection gate quickly established to protect the field
- VIPR 1

TRL 7
- First engine to test
- VIPR 6 established to better align with performance data

TRL 8
- Production implementation
- Z-score SPC on re-designed casting
Summary

• Need to be pro-active and evaluate emerging NDT technologies in a controlled manner away from the extreme pressure of a production or field inspection need – Technology Readiness

• Using Technology Readiness history P&WC was able to rapidly implement a PCRT inspection process that met the expectation of the various aviation regulatory bodies thus allowing the fleet to continue flying

• NDT is no longer just an inspect tool. It contributes significantly to the value stream and life cycle management of gas turbine aircraft engines on a daily basis
A promise founded upon excellence in quality, ethics and rigour every day!